

Clinical Prediction Model for Target Lesion Revascularization Within One Year After Drug-Eluting Stent Implantation: Nationwide Analysis Within the Netherlands Heart Registration

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Purpose: This study aimed to develop and validate a clinical prediction model for target lesion revascularization (TLR) at one-year follow-up in patients undergoing percutaneous coronary intervention (PCI) with implantation of a drug-eluting stent (DES).

Patients and Methods: Using real-world data from the Netherlands Heart Registration, we included patients treated with at least one DES between 2019 and October 2022. The study cohort comprised 96,758 patients from 29 centers, while a sub-cohort of 11,789 patients from 11 centers had additional procedural data. Multivariable logistic regression with backward stepwise selection was used for model development. Final coefficients were pooled across 20 imputed datasets, and separate models were built for both cohorts.

Results: The study cohort model included age, sex, interaction between age and sex, diabetes mellitus, renal insufficiency, multivessel disease, out-of-hospital cardiac arrest (OHCA), cardiogenic shock, previous myocardial infarction, previous coronary intervention, access site, number of treated vessels, PCI in the left main, and PCI in arterial or venous grafts. The optimism-corrected area under the curve (AUC) was 0.645 (95% confidence interval (CI): 0.633–0.657). The sub-cohort model incorporated total stent length in the left anterior descending artery, arterial or venous grafts, and left main, along with renal insufficiency, previous coronary intervention, and OHCA, yielding an AUC of 0.662 (95% CI: 0.631–0.693).

Conclusion: The developed models provide a basis for predicting one-year TLR using routinely collected data. Despite strong calibration, their modest discrimination suggests a need for more detailed variables and advanced modelling approaches to improve performance.

Keywords: percutaneous coronary intervention, target lesion revascularization, drug-eluting stents, risk assessment

Introduction

Coronary artery disease (CAD) is still the most leading cause of mortality and morbidity worldwide.¹ Patients with CAD can be treated by revascularization with percutaneous coronary intervention (PCI) using stents.²

In recent decades several developments have contributed to improved clinical outcomes following PCI, including the introduction of drug eluting stents (DES) and optimized antiplatelet therapy strategies. Nevertheless, adverse events such as in-stent restenosis (ISR) and stent thrombosis still occur at clinically relevant rates.^{3,4} Moreover, these adverse events are frequently followed by complications associated with increased morbidity, including myocardial infarction (MI) and in some cases sudden cardiac death.⁵ Importantly, the occurrence of recurrent adverse cardiac events has a significant impact on quality of life and healthcare costs.⁶

Target lesion revascularization (TLR) is a commonly used treatment in patients with adverse events like ISR and stent thrombosis. Therefore, identifying patients at high risk of TLR is crucial, as this may help clinicians optimize treatment strategies and thereby improve patient prognosis. Earlier studies revealed stent-related characteristics such as length and diameter, as well as patient-related factors such as diabetes mellitus as predictors of TLR^{7–10} Incorporating important predictive factors in a clinical prediction model may facilitate early recognition of patients at increased risk of TLR and tailor their post-PCI follow-up treatment.

The aim of this study was to develop and validate a clinical prediction model for the occurrence of TLR at one year follow-up for patients undergoing PCI with DES implantation. The model was developed using real-world data from the nationwide PCI registry of the Netherlands Heart Registration (NHR) and included only factors that are readily available in clinical practice.

Methods

Study Population

Patients who underwent PCI with at least one DES implantation between 2019 till October 2022 in the Netherlands were included in the analysis. The following patients were excluded: 1) those undergoing transcatheter aortic valve implantation (TAVI) on the same day as the PCI, 2) those with an elective PCI procedure performed within 90 days prior or post TAVI, 3) patients who died within one year without experiencing TLR, and 4) patients treated with a stent other than DES.

Study Endpoint and Potential Predictors

The primary outcome was TLR within one year, defined as any repeat PCI of the initially treated target lesion. Potential predictor variables were selected based on clinical relevance and availability in routine practice after the index procedure and insights from existing literature on TLR after PCI. The method of selection of relevant variables within the NHR is described in detail in the paper of Timmermans et al¹¹ These included: demographics (age (continuous), sex), comorbidities (renal insufficiency (estimated glomerular filtration rate (eGFR) < 60 or ≥ 60), diabetes mellitus, multivessel disease, chronic total occlusion (CTO), admission with cardiogenic shock, or admission with out-of-hospital cardiac arrest (OHCA)), medical history (previous MI, previous PCI, previous coronary artery bypass grafting (CABG)), interventional characteristics (PCI indication, access site, treated vessels, number of stents (continuous), maximum stent diameter (mm, continuous), total stent length (mm, continuous), use of calcium modification therapy, and use of intravascular imaging). All potential predictors were binary coded unless specified.

Data Source

For the current retrospective observational cohort study prospectively collected data registered within the NHR were used. The study was approved by the institutional review board Medical research Ethics Committees United (MEC-U), which originated from a collaboration between ten hospitals and one university, and was conducted in agreement with the principles of the Declaration of Helsinki (W19.270). A waiver for informed consent for analysis with the data of the NHR registry was obtained, as this retrospective study uses existing data from patients who were already registered for another purpose (quality of care). Therefore, this research is not subject to the Medical Research Involving Human Subjects Act (in Dutch: WMO). All data handling complied with applicable data protection and privacy regulations, including the General Data Protection Regulation (GDPR). Detailed information on the process of data acquisition, completeness, data quality and analysis of the NHR has been published previously.^{11,12} In short, all 29 centers in the Netherlands performing PCI procedures submit information about patient- and procedural characteristics, as well as outcomes for each intervention. The data dictionary for the PCI registry is available online via <https://www.nhr.nl/handboeken/>. Mortality data were obtained by checking the regional municipal administration registration (Basisregistratie Personen (BRP)). Follow-up was complete up to one year after PCI. Since 2020, the PCI registry was expanded with additional procedural-related variables, namely number of stents, stent length, use of imaging, and use of calcium modification therapy. A total of 11 centers collected this additional variable set. This is defined as the sub-cohort.

Statistical Analysis

Categorical data is presented as number and percentage and compared by Chi-square test. Continuous variables were evaluated for normality and presented as mean $\pm$ standard deviation (SD) or as median with interquartile range (IQR), depending on normality.

Univariable logistic regression analysis was performed to identify predictors associated with TLR at a significance threshold P -value < 0.10 . Interactions between sex and age and between sex and diabetes mellitus on the outcome were considered.

Missing data were addressed using multiple imputation with 20 imputations; outcomes were not imputed. Separate imputation models were built for the study cohort and sub-cohort; using variables identified from the univariable analyses, TLR and mortality at one year follow-up.

Model development was performed using multivariable logistic regression analysis with backward stepwise selection and adhering to a rule of at least 10 outcome events per predictor variable. Final model coefficients were estimated by pooling across the 20 imputed sets. Separate models were built for the study cohort and the sub-cohort. As a sensitivity analysis separate models were built for acute (ST-elevation myocardial infarction (STEMI) and non-STEMI) and elective patients using backwards selection within the study cohort.

Apparent performance of the models was assessed via Brier score, area under the receiver operating characteristics (ROC) curve (AUC), and Hosmer-Lemeshow goodness-of-fit test. These performance indicators were computed separately for each imputed set and pooled where applicable. To estimate optimism, 1000 bootstrap samples were drawn from the first imputed set.

All statistical analyses were performed using R Statistical Software (version 4.4.3 R Core Team 2025).

Results

We included 96,758 patients (study cohort), and for 11,789 patients additional procedural-related information was available (sub-cohort) (Figure 1). Missing data was $< 5\%$ for potential predictors, except for imaging and preparation techniques (38.4%). Incidence of TLR within one year was 2.2% and 2.5%, respectively.

The characteristics of the study population are summarized in Table 1. The study cohort and sub-cohort were comparable on baseline characteristics. The sub-cohort showed, compared to the study cohort, a slightly higher prevalence of multivessel disease (52.1% vs. 51.1%) and a lower rate of renal insufficiency (eGFR < 60) (19.8% vs. 20.9%). Also, the procedural

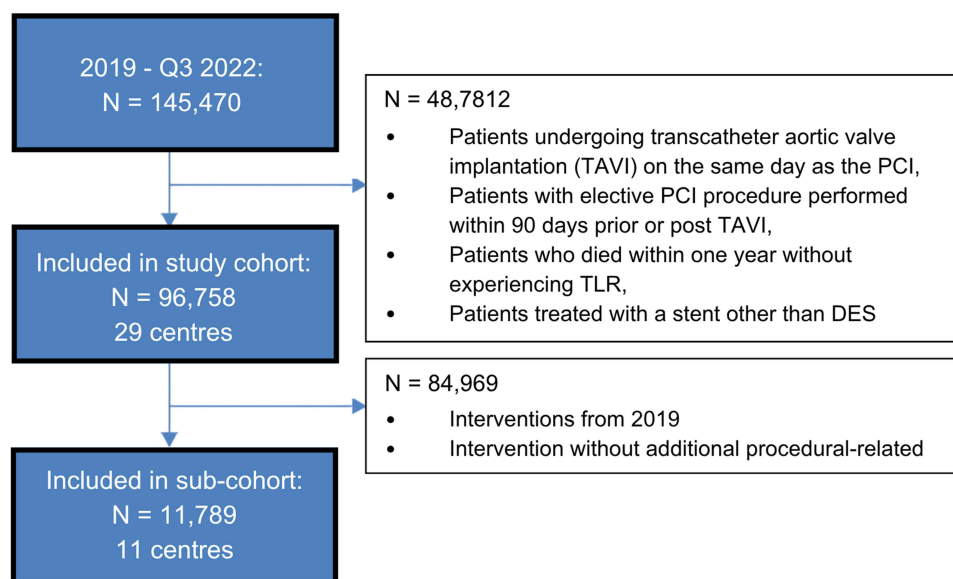


Figure 1 Flow-chart for selection of study cohort and sub-cohort of patients undergoing percutaneous coronary intervention (PCI) with drug-eluting stent implantation (DES). **Abbreviation:** TLR, target lesion revascularization.

Table 1 Patient Characteristics, Procedural Characteristics and Outcomes Study Cohort (N = 96,758) and Sub-Cohort (N = 11,789) of Patients Undergoing Percutaneous Coronary Intervention with Drug-Eluting Stent Implantation

	Study Cohort, 2019-Q3 2022 (N = 96,758)	Sub-Cohort 2020-Q3 2022 (N = 11,789)
<i>Patient characteristics</i>		
Age in years, mean (SD)	66 (11)	66 (11)
Cardiogenic shock, n (%)	1997 (2.1%)	272 (2.3%)
Diabetes mellitus, n (%)	20,683 (21.5%)	2508 (21.3%)
Sex (female), n (%)	26,328 (27.2%)	3129 (26.5%)
Multivessel disease, n (%)	49,288 (51.1%)	6140 (52.1%)
Renal insufficiency (eGFR <60), n (%)	19,788 (20.9%)	2298 (19.8%)
Previous coronary intervention (PCI and/or CABG), n (%)	26,646 (27.6%)	3300 (28.0%)
Previous MI, n (%)	19,603 (20.4%)	2479 (21.1%)
OHCA, n (%)	2639 (2.7%)	311 (2.6%)
<i>Procedural characteristics</i>		
Access site, n (%)		
• Radialis	86,121 (89.1%)	10,337 (87.7%)
• Femoralis	10,355 (10.7%)	1433 (12.2%)
• Other	205 (0.2%)	16 (0.1%)
CTO, n (%)	4187 (4.3%)	527 (4.5%)
IVUS, n (%)	n.a.	183 (2.5%)
OCT, n (%)	n.a.	88 (1.2%)
Calcium modification therapy, n (%)	n.a.	192 (2.6%)
PCI indication, n (%)		
• Elective	34,372 (35.6%)	4155 (35.2%)
• Non-STEMI	33,545 (34.8%)	4008 (34.0%)
• STEMI	28,582 (29.6%)	3626 (30.8%)
Single vessel treatment, n (%)	82,085 (84.8%)	10,074 (84.0%)
Stent length in mm, median (IQR)	n.a.	37.1 (18–46)
Maximum stent diameter in mm, median (IQR)	n.a.	3.2 (3–3.5)
Number of stents implanted, median (IQR)	n.a.	1.6 (1–2)
Treated vessels, n (%)		
• AL/IM	2614 (2.7%)	334 (2.8%)
• LAD	47,559 (49.2%)	5888 (49.9%)
• LM	3938 (4.1%)	535 (4.5%)
• RCA	33,908 (35.0%)	4157 (35.3%)
• RCX	23,411 (24.2%)	2852 (24.2%)
• Arterial or venous grafts	1876 (1.9%)	193 (1.6%)

(Continued)

Table 1 (Continued).

	Study Cohort, 2019-Q3 2022 (N = 96,758)	Sub-Cohort 2020-Q3 2022 (N = 11,789)
<i>Study outcome</i>		
TLR, n (%)	2099 (2.2%)	289 (2.5%)

Abbreviations: SD, standard deviation; eGFR, estimated glomerular filtration rate; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; MI, myocardial infarction; OHCA, out of hospital cardiac arrest; CTO, chronic total occlusion; IVUS, intravascular ultrasound; OCT, optical coherence tomography; STEMI, ST-elevation myocardial infarction; IQR, interquartile range; AL/IM, anterolateral/intermediate branch; LAD, left anterior descending; LM, left main; RCA, right coronary artery; RCX, ramus circumflexus; TLR, target lesion revascularization.

characteristics were comparable between the two cohorts, with some differences on access site, PCI indication, and incidence of treatment of the left main vessel.

In total, 17 potential predictors were selected based upon availability within the NHR database for the study cohort, and 20 potential predictors were available for the sub-cohort ([Supplement Material 1](#) and [Table S1](#)). Univariable logistic regression analysis revealed the following characteristics to be associated (P -value < 0.1) with TLR within one year after PCI: age, interaction between age and sex, renal insufficiency (eGFR < 60), diabetes mellitus, multivessel disease, cardiogenic shock, OHCA, previous MI, previous coronary intervention, access site, PCI in left main vessel, PCI in arterial or venous grafts, number of treated vessels, and stent length (total and total length per treated vessel). Odds ratios and corresponding 95% confidence intervals (CIs) are presented in [Table 2](#).

Table 2 Univariable Analysis of the Relation Between Target Lesion Revascularization (TLR) Within One Year After Percutaneous Coronary Intervention (PCI) and Patient or Procedural Characteristics

Patient Characteristics	OR	95% CI		P-value
Sex (Female)	1.01	0.92	1.11	0.811
Age (years, linear)	1.01	1.01	1.01	<0.001
Age * Sex	0.98	0.97	0.99	<0.001
Diabetes mellitus	1.79	1.63	1.97	<0.001
Sex * Diabetes mellitus	1.02	0.83	1.25	0.876
Renal insufficiency (eGFR < 60)	1.42	1.29	1.57	<0.001
Multivessel disease (no)	0.59	0.54	0.64	<0.001
Cardiogenic shock	1.79	1.40	2.24	<0.001
OHCA	1.39	1.09	1.73	0.005
Previous MI	1.83	1.67	2.01	<0.001
Previous coronary intervention (PCI and/or CABG)	2.08	1.91	2.27	<0.001

(Continued)

Table 2 (Continued).

Patient Characteristics	OR	95% CI		P-value
<i>Procedural characteristics</i>				
PCI indication				
• Elective	reference			
• Non-STEMI	1.01	0.91	1.12	0.853
• STEMI	0.98	0.88	1.10	0.779
CTO	1.01	0.82	1.24	0.899
Access site (other than radialis)	1.88	1.68	2.10	<0.001
PCI in LAD	1.04	0.96	1.14	0.349
PCI in LM	2.21	1.88	2.58	<0.001
PCI in RCX	1.04	0.94	1.14	0.499
PCI in AL/IM	1.04	0.79	1.34	0.755
PCI in RCA	0.96	0.88	1.05	0.389
PCI in arterial or venous grafts	3.54	2.94	4.24	<0.001
Number of treated vessels				
One	reference			
Two	1.41	1.26	1.58	<0.001
Three or more	2.84	2.28	3.48	<0.001
<i>Additional procedural characteristics</i>				
IVUS	1.48	0.57	3.10	0.358
OCT	1.00	0.16	3.20	1.000
Calcium modification therapy	2.73	1.37	4.89	0.002
Total stent length (mm, linear)	1.01	1.00	1.01	0.013
Stent length in LAD (mm, linear)	1.01	1.00	1.01	0.016
Stent length in LM (mm, linear)	1.03	1.02	1.04	<0.001
Stent length in RCX (mm, linear)	1.00	0.99	1.01	0.821
Stent length in AL/IM (mm, linear)	0.99	0.95	1.02	0.743
Stent length in RCA (mm, linear)	1.00	0.99	1.00	0.524
Stent length in arterial or venous grafts (mm, linear)	1.03	1.01	1.05	0.003
Maximum stent diameter (mm, linear)	0.87	0.68	1.10	0.247

Abbreviations: OR, odds ratio; CI, confidence interval; eGFR, estimated glomerular filtration rate; OHCA, out of hospital cardiac arrest; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; STEMI, ST elevation myocardial infarction; CTO, chronic total occlusion; LAD, left anterior descending; LM, left main; RCX, ramus circumflexus; AL/IM, anterolateral/intermediate branch; RCA, right coronary artery; IVUS, intravascular ultrasound; OCT, optical coherence tomography; mm, millimetre.

Model Study Cohort

The final prediction model for TLR based on the study cohort included: sex, age, interaction between age and sex, renal insufficiency (eGFR < 60), multivessel disease, previous MI, number of treated vessels (two/three or more), OHCA, PCI in left main vessel, access site (other than radialis), diabetes mellitus, previous coronary intervention, cardiogenic shock and PCI in arterial or venous grafts. Model coefficients and odds ratios are presented in [Table 3](#). The densities of the predicted probability are plotted in [Figure 2A](#).

Mean Brier score was 0.021 across imputations indicating strong accuracy of the model. The average AUC across imputations was 0.644 (95% CI: 0.644–0.644) indicating limited discriminatory power. The optimism corrected AUC based on the bootstrap estimate was 0.645 (95% CI: 0.633–0.657). The Hosmer-Lemeshow *P*-values ranged from 0.291 to 0.675 across imputations, with a mean of 0.525, suggesting good model calibration.

Sensitivity Analysis

Separate models were built for acute (STEMI and non-STEMI) and elective patients. The final model for acute patients included the same predictors as discovered in the study cohort ([Supplement Material 2](#) and [Table S2](#)). For elective patients the following predictors were removed in the final model: renal insufficiency (eGFR < 60), OHCA, cardiogenic shock, previous MI, and PCI in left main vessel ([Supplement Material 2](#) and [Table S3](#)).

Table 3 Results of Multivariable Logistic Regression Analysis for Target Lesion Revascularization (TLR) Within One Year After Percutaneous Coronary Intervention (PCI), Study Cohort

Variable	OR	95% CI	Regression Coefficient	P-value
Intercept			−4.68	
Age (years) [#]			4.23e-03	
Sex (Female) [#]			1.22	
Age*Female	0.98	(0.97–0.99)	−0.02	<0.001
Renal insufficiency (eGFR <60)	1.12	(1.01–1.25)	0.12	0.031
Diabetes mellitus	1.50	(1.362–1.65)	0.41	<0.001
Multivessel disease	1.17	(1.05–1.30)	0.15	0.004
Cardiogenic shock	1.62	(1.26–2.09)	0.48	<0.001
OHCA	1.33	(1.04–1.70)	0.29	0.024
Previous MI	1.18	(1.06–1.33)	0.17	0.004
Previous coronary intervention (PCI and/or CABG)	1.52	(1.35–1.70)	0.42	<0.001
Access site (other than radialis)	1.38	(1.23–1.56)	0.32	<0.001
PCI in LM	1.37	(1.14–1.64)	0.31	0.001
PCI in arterial or venous grafts	2.01	(1.73–2.55)	0.74	<0.001
Two vessels treated	1.20	(1.06–1.37)	0.18	0.005
Three or more vessels treated	2.06	(1.62–2.61)	0.72	<0.001

Notes: [#]Age and sex can not be interpreted separately due to the presence of the interaction term Age*Sex.

Abbreviations: OR, odds ratio; CI, confidence interval; eGFR, estimated glomerular filtration rate; OHCA, out of hospital cardiac arrest; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; LM, left main.

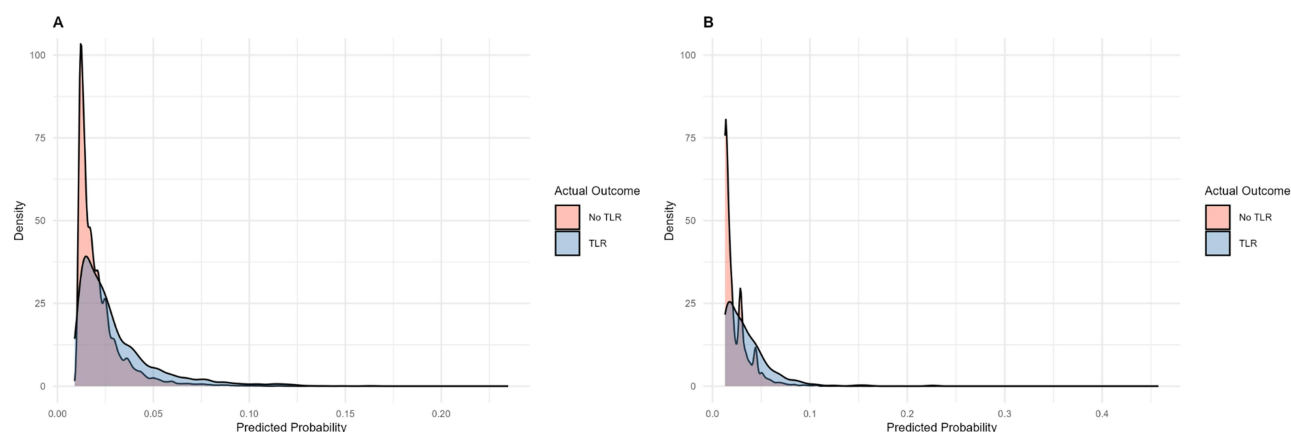


Figure 2 Density plot for predicted probability obtained from the logistic regression analysis for target lesion revascularization (TLR) within one year after percutaneous coronary intervention (PCI).

Notes: (A) Results study cohort, (B) Results sub-cohort.

Model Sub-Cohort

The final prediction model for TLR based on the sub-cohort included: renal insufficiency (eGFR < 60), previous coronary intervention, OHCA, total stent length in LAD, total stent length in arterial or venous grafts, and total stent length in the left main. Model coefficients and odds ratios are presented in Table 4. The densities of the predicted probability are plotted in Figure 2B.

Mean Brier score was 0.024 across imputations indicating strong accuracy of the model. The average AUC across imputations was 0.662 (95% CI: 0.661–0.663) indicating limited discriminatory power. The optimism corrected AUC based on the bootstrap estimate was 0.662 (95% CI: 0.631–0.693). The Hosmer-Lemeshow *P*-values ranged from 0.025 to 0.615 across imputations, with a mean of 0.268, suggesting good model calibration.

Discussion

In this large-scale, registry-based, nationwide analysis of >95,000 patients undergoing a PCI with DES, we identified several key predictors of TLR one-year post-PCI and developed multiple models. These models provide a basis for predicting one-year TLR using routinely collected clinical and procedural data. Our models demonstrated good calibration with acceptable accuracy but limited discriminative power.

Table 4 Results of Multivariable Logistic Regression Analysis for Target Lesion Revascularization (TLR) Within One Year After Percutaneous Coronary Intervention (PCI), Sub-Cohort

Variable	OR	95% CI	Regression Coefficient	P-value
Intercept			−4.35	
Renal insufficiency (eGFR <60)	1.57	(1.21–2.04)	0.45	0.001
OHCA	2.61	(1.57–4.36)	0.96	<0.001
Previous coronary intervention (PCI and/or CABG)	2.30	(1.80–2.94)	0.83	<0.001
Stent length in LAD (mm)	1.01	(1.00–1.01)	0.01	0.001
Stent length in LM (mm)	10.2	(1.01–1.04)	0.02	0.002
Stent length in arterial or venous grafts (mm)	1.02	(1.00–1.04)	0.02	0.036

Abbreviations: OR, odds ratio; CI, confidence interval; eGFR, estimated glomerular filtration rate; OHCA, out of hospital cardiac arrest; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; LAD, left anterior descending; mm, millimetre; LM, left main.

Our findings reaffirm several previously reported patient-related predictors of TLR, including age, sex, diabetes mellitus, multivessel disease, cardiogenic shock, renal insufficiency, and previous coronary intervention or MI.^{7,13–15} Notably, stent length in the treated vessels appears to be more influential than certain patient characteristics in our study, underscoring the importance of anatomic burden as a key determinant.^{16,17} This observation is consistent with other studies focusing on developing TLR prediction models. For instance, the model proposed by Stolker et al¹⁸ includes age and previous PCI as the only patient-related variables, while procedural factors such as left main PCI, arterial or venous grafts, and total stent length contribute significantly. Their model demonstrated comparable performance (c-statistic: 0.633). External validation using our dataset was not feasible due to the absence of minimum stent diameter data, only maximum stent diameter was available.

Another study performed by Dake et al¹⁹ developed a multivariate Cox regression model to predict TLR up to five years post-PCI. Their findings highlighted lesion-specific factors such as lesion length, Rutherford classification, and reference vessel diameter as having the greatest impact. Among patient characteristics, only age, sex, and prior intervention remained significant. Notably, they included total occlusion (TO) as a relevant factor, which encompasses both acute and chronic occlusions. In contrast, our study specifically focused on CTO, defined as occlusions persisting for more than three months, which were present in only 4.3% of our cohort and did not show a statistically significant association in univariate logistic regression analysis. This difference in definition and prevalence may partly explain the discrepancy in predictiveness. The J-CTO score,²⁰ which reflects the complexity of CTOs, was unfortunately unavailable in both cohorts, precluding direct comparison. At the one-year mark, the model of Dake et al showed slightly better performance compared to ours (AUC: 0.668).

Our model complements existing risk scores such as GRACE Risk (2.0),²¹ TIMI Risk score,^{22,23} and CRUSADE,²⁴ which are primarily designed to assess mortality and bleeding risk in acute coronary syndrome (ACS). These tools assist cardiologists in clinical decision-making regarding treatment strategy, for example, selecting the optimal antiplatelet regimen based on the CRUSADE score or prioritizing early revascularization for patients with a high GRACE score. In a similar vein, the models described in the current study can assist cardiologists in identifying patients at risk of TLR and tailoring their post-PCI management accordingly. The strength of our model is that it also accounts for procedural and anatomical factors, in contrast to the currently available risk scores, which lack this level of granularity.²⁵

Nonetheless, the modest discriminatory performance of both our model and those previously published raises important questions about their clinical utility. As shown in the density plot of our study, there is a lot of overlap in the predicted probabilities, suggesting limited ability to differentiate between high- and low-risk patients. This indicates that the currently available variables may still not fully capture the biological and structural complexities underlying stent failure. Since identifying high-risk patients can help clinicians optimize treatment strategies and potentially improve patient prognosis, enhancing prediction models remains a critical goal. To achieve this, the integration of angiographic factors may be key to improving the accuracy of TLR risk assessment.^{26,27}

Risk prediction may potentially be further enhanced by incorporating intracoronary imaging variables, which can provide more accurate estimations of true vessel and stent dimensions during PCI. However, most PCI procedures are currently still guided by angiography alone.²⁸ Similarly, in our study the use of the two imaging modalities, intravascular ultrasound (IVUS) and optical coherence tomography (OCT) were used in only a minority of the PCIs (2.5% and 1.2%, respectively). Although several recent studies have reported associations between the use of intracoronary imaging during PCI and lower TLR rates in complex lesions, it remains uncertain whether such data would meaningfully improve model discrimination.^{14,29,30} As its application is expected to increase in the coming years, future availability of more intracoronary imaging data may allow for further model refinement.²⁸

Target lesion calcification is associated with increased TLR risk, as calcified lesions are more prone to stent malapposition and underexpansion.^{31–33} Calcium modification techniques can be used to optimize lesion preparation and improve the likelihood of achieving full stent expansion after implantation.³⁴ In our sub-cohort, the use of calcium modification was limited to 2.6%. Coronary calcification can be scored based on angiography and on intracoronary imaging, however, such detailed information was not available in the current study. Incorporating information on coronary calcification could potentially contribute to TLR risk estimation, but its incremental predictive value remains to be established.

Future studies should evaluate whether integrating lesion complexity, intracoronary imaging, and calcium modification techniques into predictive models offers meaningful improvements in the discriminatory ability towards stent failure and TLR. More advanced modelling approaches, such as random forest algorithms, may facilitate model development. However, it remains crucial to translate complex models into easily applicable risk scores for routine clinical use.

Study Limitations

Our study findings should be interpreted in light of several limitations. Firstly, due to the retrospective observational design of the study, not all potential predictive factors for TLR were available. Consequently, important variables may be missing from our model. Nevertheless, all included factors are accessible in clinical practice and thus readily applicable. Secondly, it was not possible to distinguish TLR due to in-stent restenosis. Other contributing factors may be relevant to this outcome. Since 1 July 2023, the PCI registry of the NHR has been updated to separately record in-stent restenosis, enabling future studies to differentiate between these outcomes. Thirdly, the one-year follow-up period limits our ability to predict later TLR events, occurring beyond this timeframe.

Conclusion

The developed models provide a basis for predicting one-year TLR following PCI with DES, using only routinely collected clinical and procedural data. Despite strong calibration, the modest discriminatory performance highlights the need for more detailed variables and advanced modelling approaches to improve performance. Future research should aim to evaluate if incorporate lesion complexity and imaging modalities, amongst others, enhance predictive accuracy, while ensuring models remain feasible for clinical implementation post-PCI.

Data Sharing Statement

The data underlying this article were provided by the NHR with the permission of the participating centers. Data are available upon reasonable request to the corresponding author and with permission of the NHR.

Acknowledgments

This study was carried out on behalf of the PCI Registration Committee of the Netherlands Heart Registration.

Collaborators

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